DESIGN AND CONSTRUCTION OF A RADIO TELEPHONE STATION

BY

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ARMOUR INSTITUTE OF TECHNOLOGY

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THE DESIGN AND CONSTRUCTION OF A RADIO TELEPHONE STATION

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A THESIS

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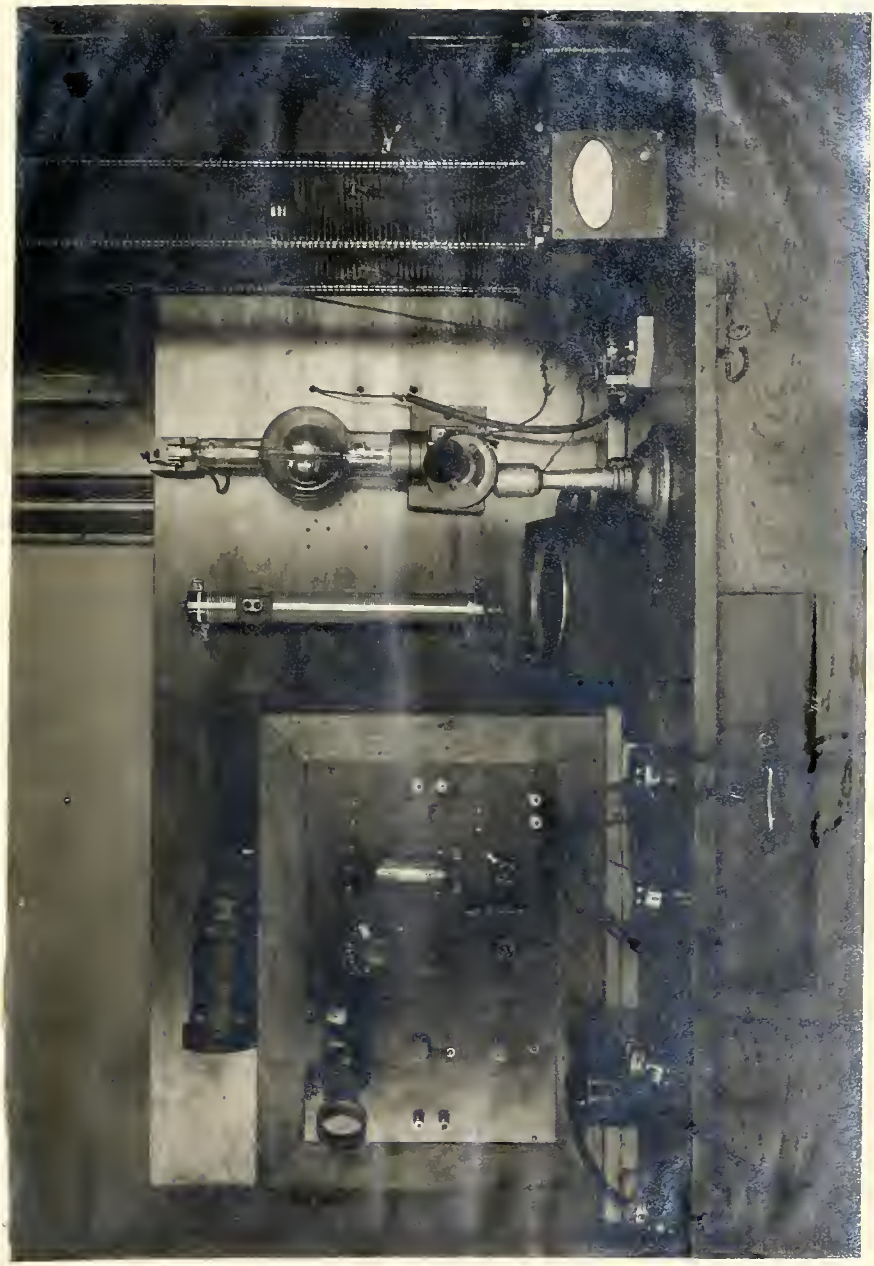
OBJECT

The object of this thesis is to design, construct, and operate a radio telephone station at Armour Institute of Technology, Chicago, Ill.



1. INTRODUCTION

Although a great number of experiments have already been performed with the regular wireless telegraph set which was installed in the year 1920, the wireless classes have been unable to carry on any wireless telephone experiments, due in part to lack of apparatus, and also in part, to lack of time necessary for the calculations and construction work incident to the installation of a wireless telephone set.

In constructing the set, the apparatus belonging to the physics department was used in addition to several pieces constructed or purchased when necessary. The station is located in a room of the Physics Laboratory on the second floor of Chapin Hall. The antennae are supported above Chapin Hall and the Mission Building by wooden masts and one of the towers on the Armour Flats. Calibration curves, diagrams, photographs, circuit constants, etc., have been made for the set. Thus should the apparatus be taken apart at any time, it can readily be set up again without recalculating.

The former government license allowed a wave length of from 200 to 375 meters, but the wave length has since been extended to 600 meters.

2. HISTORY

The term "Wireless Telephony" means, in general, the transmission of human speech to great distances without the use of a connecting wire between the sending and receiving stations.

In the simplest cases, the air serves as a carrier of the sound waves, while the voice of the speaker is the transmitter and the ear of the hearer is the receiver.

The earliest forms of the radio telephone were due to the discovery of the "singing arc." This phenomenon was first observed by Lecher, and was more thoroughly investigated later by Duddell and Peuckert. It consists essentially in the production of a nearly sinusordal alternating current in a circuit containing inductance and capacity in parallel with the arc. In like manner oscillations are produced in an organ pipe by the action of a steady current of air connected to a vibrating system having a definite period

of vibration. The arc serves to convert the continuous current into an alternating current, and is according to Heinke's classification, a wave producer of the "second order," the high-frequency generator belonging to the first order.

It was after the singing arc had been utilized for the purpose of producing electrical oscillatory currents, that wave telephony became practical. Quite recently three methods have been discovered by means of which the frequency of the arc vibrations may be increased sufficiently for this purpose, and these we shall consider before explaining their application to wireless telephony.

Poulson Generator

Poulsen was the first to solve the problem of the production of relatively intense oscillations of high frequency by means of the Duddell phenomenon by placing the arc in an atmosphere consisting of a gas of high thermal conductivity instead of air (patented Dec. 15, 1902). Hydrogen or one of its compounds was

found to be the best.

In order to increase the radiation still further, Poulsen used several arc in series in an atmosphere of hydrogen.

Application of the Arc to Telephony

The first successful experiments on the the application of the arc to wireless telephony were made by Ruhmer in the summer of 1906. His apparatus was hooked up as shown in Figure 1. The attempt was very successful and with an aerial only 15 meters long speech was transmitted over a distance of 30 meters. The receiving appartus is shown in Figure 1.

In December, 1906, the experiment was carried on between two dwelling houses in Berlin at a distance of about 500 meters from each other. The transmission of speech was perfect. In this way the arc sets were developed until they reached a high degree of perfection.

Hetereodyne Receiver

In about the year 1903 Prof. Fessenden

RUHMER'S TRANSMITTER

RUHMER'S RECEIVER

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FIG. 1

invented his Hetereodyne Receiver. It is an ingenious adaptation of the ordinary Bell Telephone Receiver to the purpose of wireless telephony. He was led to its invention by a consideration of the great inefficiency of even the most sensitive of detectors, and of their insensibility as compared with a telephone. Thus while a liquid barretter or a magnetic receiver will give an indication with between .01 and .001 of an erg, an ordinary telephone receiver will produce an audible sound with less than .000001 erg.

The Hetereodyne consists of two small coils of wire, one of which is wound around a fixed core of very fine iron wires; the other, whose plane is parallel to that of the first, is attached to a mica diaphragm. A high frequency current from a local source is maintained, in the first coil, while the second is traversed by the current from the receiving aerial. The frequency of the local current is kept constant and within a few per cent. of the normal frequency of the transmitter, and therefore, of the received current. Thus when the frequency or amplitude

of the transmitted current is altered by the action of the voice in speaking, the mechanical force between the two coils of the received varies in a like manner, and the result is a reproduction of the sound by the mica diaphragm.

Development of Arc Telephony

The arc telephone developed very rapidly after the first few experiments. Many different variations of the original scheme were experimented upon with varied success. Among the successful ones are those of the Telefunken Company and of Colin and Jeance.

Radio Frequent Sparks

It has occurred to a number of investigators that practically sustained radiation could be secured in an antenna by using spark transmitters, but having these transmitters so arranged that the extremely high frequency of the sparks (above audibility) would render the usual spark tone inaudible. If, then the antenna energy were modulated by a microphone or otherwise, radio telephony would become possible. Mar-

coni was one of the first to develop this method and was very successful.

High Frequency Alternator

The high frequency alternator took a long time in its development. The reasons for this are apparent upon reviewint the bad points in any generator. Thus it can be seen that if we want say a 100,000 cycle alternator, of ordinary size (rotor diam. 2 ft.), and we assume a speed of 2500 r. p. m., we will get a pole pitch having the extremely small value of .016 inch, which i s entirely impracticable when one considers that the wire and insulation must all be crowded into the winding slot. In addition, there would have to be 4800 poles. The foregoing reasons lead to the conclusion that inductor type alternators are the only practicable type, as they permit of an extremely high speed of rotation, in this way cutting down the necessary number of poles and increasing the size of the slots.

Vacuum Tube Oscillators

Within the last few years vacuum tubes have taken a tremendous leap of progress as sus-

tained wave radio frequency generators. The original valve was brought out by Fleming who used only one electrode inside of the bulb beside the filament.

The control of the elction stream was not very good in the original valve and it was not until Dr. Lee De Forest brought out his three electrode or " 3 element" bulb that the valve came into fovor. Since them different types of high vacuum bulbs have been brought out notably by the General Electric Company. These of the pliotron and Dynatron type have come into general use for sustained wave generation.

<u>Conclusion</u>

It was during the recent World War that the greatest advances in wireless telephony were made, due, no doubt, to the old adage that "necessity is the mother of invention." From the present day outlook it seems as if the vacuum tube will supersede all other methods of generating sustained waves, because its ease of control and dependability.

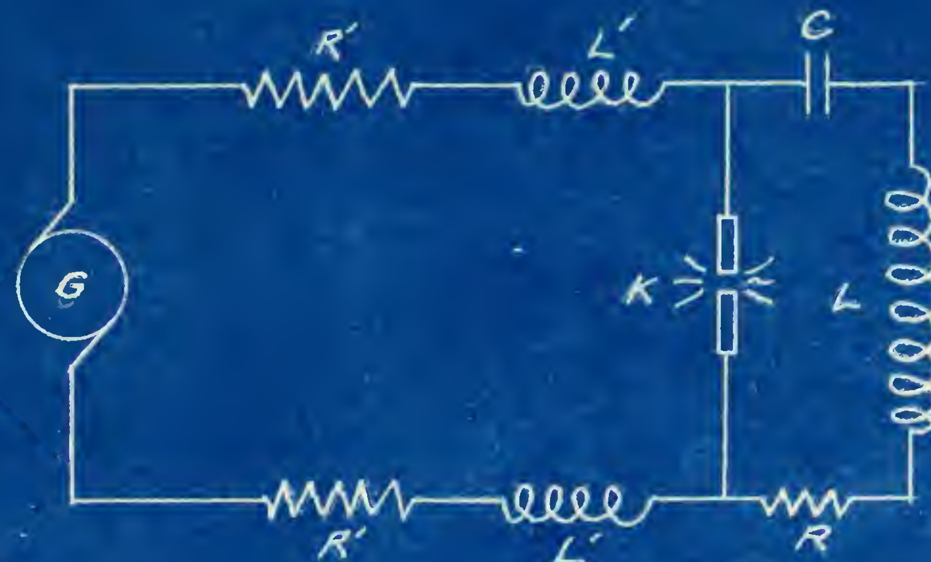
3. METHODS IN USE

All radio telephone methods consist first, of a source of high frequency alternating current, and second, of some method of modulating this current so as to produce a wave of radio-frequency. The high frequency alternating currents may be produced in the following ways:-

1. Arcs
2. Radio-Frequent Sparks
3. Vacuum Tube Oscillators
4. Alternators of Radio Frequency

(1) Arcs

The simplest generator of radio frequency oscillations of large power is the Duddell-Poulsen Arc shown in Figure 2. Here G is a d.c. generator, "R' is the resistance controlling the arc current, and "L' is a choke coil for keeping the a. c. out of the generator and also for steadying the supply voltage. The Duddell arc, "K", has solid carbon electrodes. "L," "C," and "R" are inductance, capacity, and resistance inserted



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DUDDELL ARC

FIG. 2.

in the arc shunt circuit. Their values must be carefully chosen.

"If the arc be lit, it is found th at an alternating current appears in the shunt circuit, and if the frequency of this current is within the limits of audibility, a pure singing tone will be heard."

The arc differs from ordinary conductors in one essential respect. If we divide the voltage across the terminals of an ordinary metallic conductor by the current flowing thru the conductor, the quotient is found to be a constant quantity called the resistance of the conductor. This is the case regardless of the values of voltage and current (under ordinary conditions). In the arc, the quotient is by no means constant. For higher voltage the arc resistance is large and very little current passes thru the arc under such voltages. As the voltage decreases, the resistance decreases greatly, and the current tends to increase indefinitely up to the point of a short circuit. We conclude, there-

fore, that a small increase in voltage causes a small decrease in current, and this property is sometimes called the "negative resistance" of the arc.

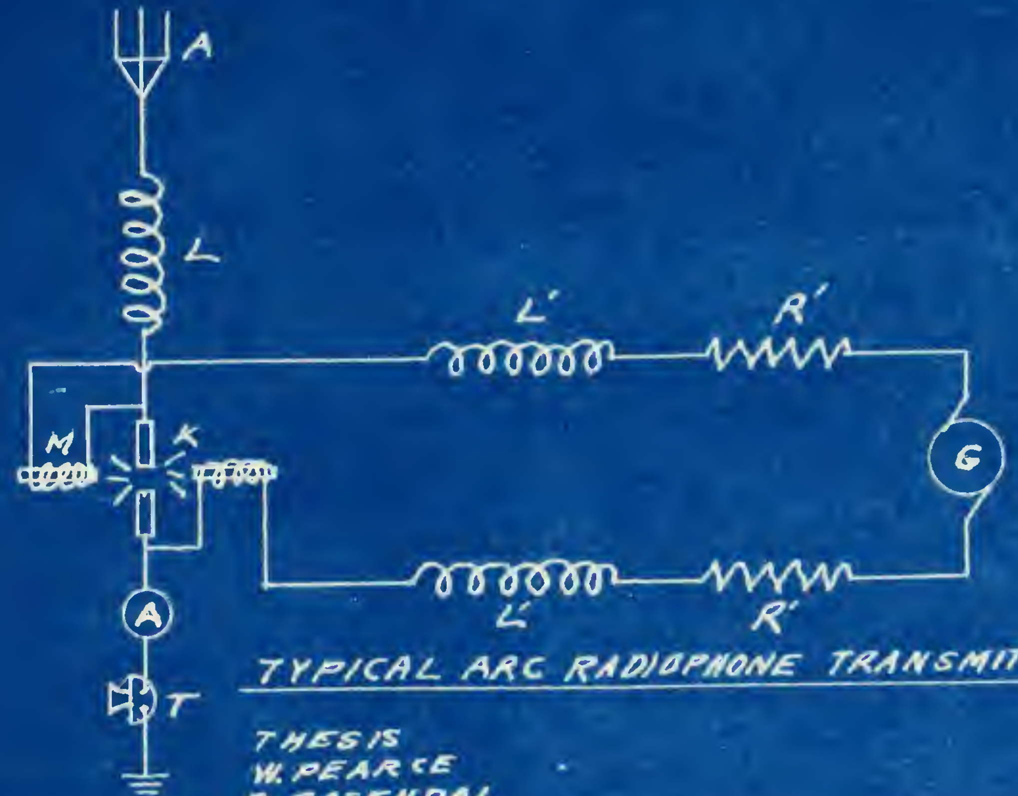
The theory of the singing arc is as follows: When the condenser and the inductance in the shunt circuit are connected to the arc, the condenser begins to accumulate a charge, and therefore robs the arc of a part of its current, since the supply current is kept appreciably constant by the presence in the supply lead of the choke coil "L′." If the current through the arc decreases, it is clear from the foregoing considerations that the voltage at its terminals must increase. Consequently, as long as the charging of the condenser continues, the arc voltage will rise. As soon as the condenser is fully charged, the arc voltage becomes stationary. Then the condenser begins to discharge itself thru the arc, thereby increasing the arc current and diminishing the voltage. The shunt current being a true periodic or oscillatory

circuit, the discharge of the condenser will continue past the point of zero current, and there will be an actual reversal of current. Thus the condenser becomes charged in the negative direction until the arc voltage falls over so far that the supply voltage of the d. c. generator causes a reversal of the whole action. The cycle is then with a frequency related to a certain extent to the natural oscillations of the shunt circuit. The vibration which takes place is closely analagous to the action in an organ pipe of the reed type.

In Figure 3 is shown a typical arc radiophone station. The arc "K" is shown in the magnetic field due to the coils "M." "A" is an ammeterfor measuring the antenna current, and "T" is a heavy current transmitter usually of the carbon microphone type.

(2) Radio-Frequent Sparks

Imagine a special form of spark gap and associated circuit so arranged that discharges occurred more or less regularly across the gap at an average frequency of say 50,000 sparks



TYPICAL ARC RADIOPHONE TRANSMITTER

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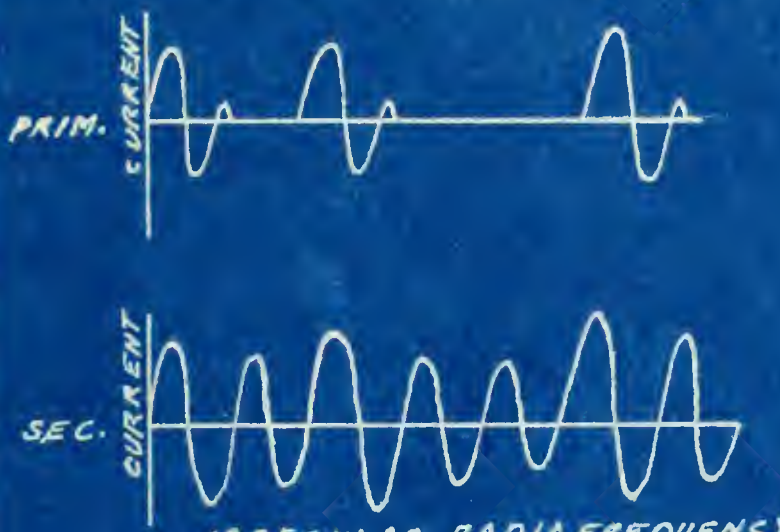
FIG. 3

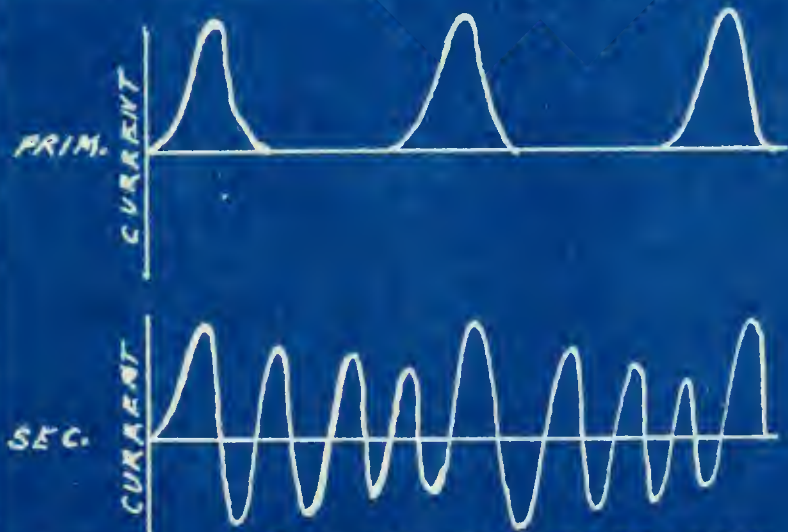
per second. If the circuit in which these sparks occurred were connected inductively to an antenna, there would be produced, in the antenna, practically sustained radiation, susceptible to suitable telephone modulation by a microphone transmitter or otherwise.

In Figure 4 is given a graphic picture of the effects. It will be noticed that highly damp3d oscillations occur rather irregularly in the primary circuit, and that each of these short oscillation groups starts a decadent wave train which has still a large current amplitude when the succeeding spark takes place. Inasmuch as the sparks follow each other so frequently, and since the antenna circuit damping is low, the effect at the distant receiver would be appreciably that of sustained radiation at the transmitter, and particularly is this the case since the changes in antenna radiation occur above andio frequency. Most of the radio-frequent spark transmitters for radio telephony operate in the fashion indicated, but there is a second special case, which has certain interesting features. It is illustrated in Figure 5, and occurs with the Chaffee "arc" (a spark phenomenon),. To begin



IRREGULAR RADIO FREQUENCY
SPARK EXCITATION OF ANTENNA.

FIG. 4



REGULAR RADIO FREQUENCY
IMPULSE EXCITATION OF ANTENNA

FIG. 5

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with, in this case the spark gap has such excessively high intrinsic damping that the spark discharges in the primary circuit tend to be aperiodic.

The radio frequent method was still further advanced by Fessenden, who in the Fall of 1900 succeeded in transmitting speech over one mile. He used a special interrupter which gave him as many as 10,000 regular sparks per second. The quality of the speech was poor, however, and there was much noise. By 1903 better speech was obtained, though the extra noise was still present. It does not appear that Fessenden developed this method further, although he describes a special rotary gap with 40% platinum iriduim studs operated on 5,000 volts direct current and arranged to give 20,000 sparks per second by the successive charging and discharging of a condenser.

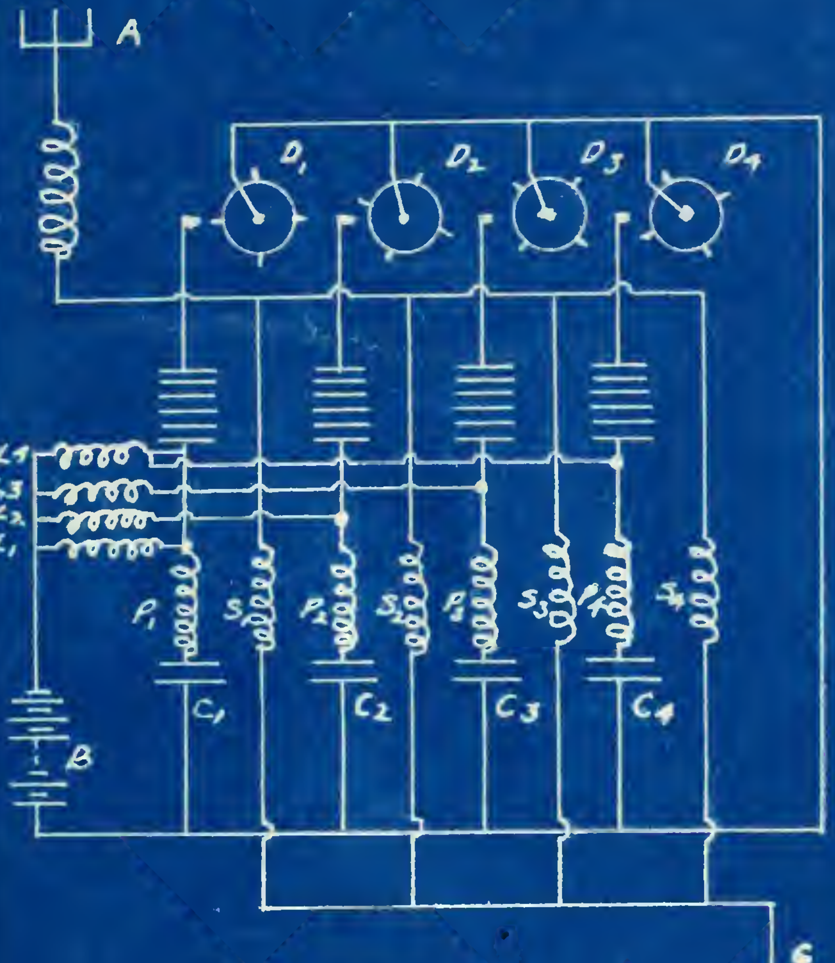
The Marconi "timid spark" method is very ingenious. There are four primary circuits damped wave trains. These four primaries are so arranged that their maximum points occur at equal intervals between waves. The result is that when the four

waves are superimposed upon the common secondary, the resultant secondary wave is of practically constant amplitude. A diagram of his connections is shown in Figure 6. The dischargers, "D_1," "D_2," etc., are similar to the regulation rotary gap except that they are all on the same shaft and they are shifted so that studs on successive discs come opposite the discharge electrode at times corresponding to one quarter of the angular distance between studs. This method has not been used very much in wireless telephony but it may be used a great deal more in the near future.

(3) Vacuum Tube Oscillators

After it was discovered that the vacuum tube could be used for producing a high frequency undamped wave, this method came to the foreground, especially for wireless telephone work. This was because of its ease of control and greater efficiency and freedom from external noises.

There are at least two available methods of controlling the output of vacuum tube oscillators



MARCONI TIMED SPARK

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FIG. 6

and instances of each of these in practice will be described. The first of these is by variation of the grid potential, the assumption being that as the grid potential becomes increasingly negative, the current through the tube (and therefore the available radio frequency output) continuously and proportionately diminishes. Difficulties of stability of operation, however, arise and the conclusion must be somewhat modified. The second of these methods is by varying the plate potential, the assumption in this case being that as the plate potential becomes increasingly positive, the current through the tube, (and therefore the available radio frequency output) continuously and proportionately increases. This conclusion also requires some modification, because of temperature and space charge limitation of plate current, and because of the limits of available energy which must be thus introduced into the plate circuit.

There are a number of differences between the operation of the two systems of modulation

mentioned such as the relation between the modulated radio frequency energy and the necessary controlling audio frequency energy, but these differences will best be brought out in considering the actual systems in use.

In Figure 7 is given the detailed wiring of a Marconi radiophone transmitter. It will be seen that oscillations are produced by coupling the grid circuit "L' C" with the plate circuit "L'' C'" by means of the inductive coupling "L' L''". The grid circuit also contains the 30 volt battery "B'" and the 3500 ohm resistance "R_1'" which latter is shunted by a suitable by-pass condenser (the regulation grid-leak) permitting the transfer of radio frequency currents but preventing excessive direct grid current. Similarly, the plate circuit also contains the resistance "R_1," "R_2," "R_3," each of which is 500 ohms, and the resistance "R_4" of 10,000 ohms. These prevent excessive plate current, "blue glow," and tube breakdown. In series

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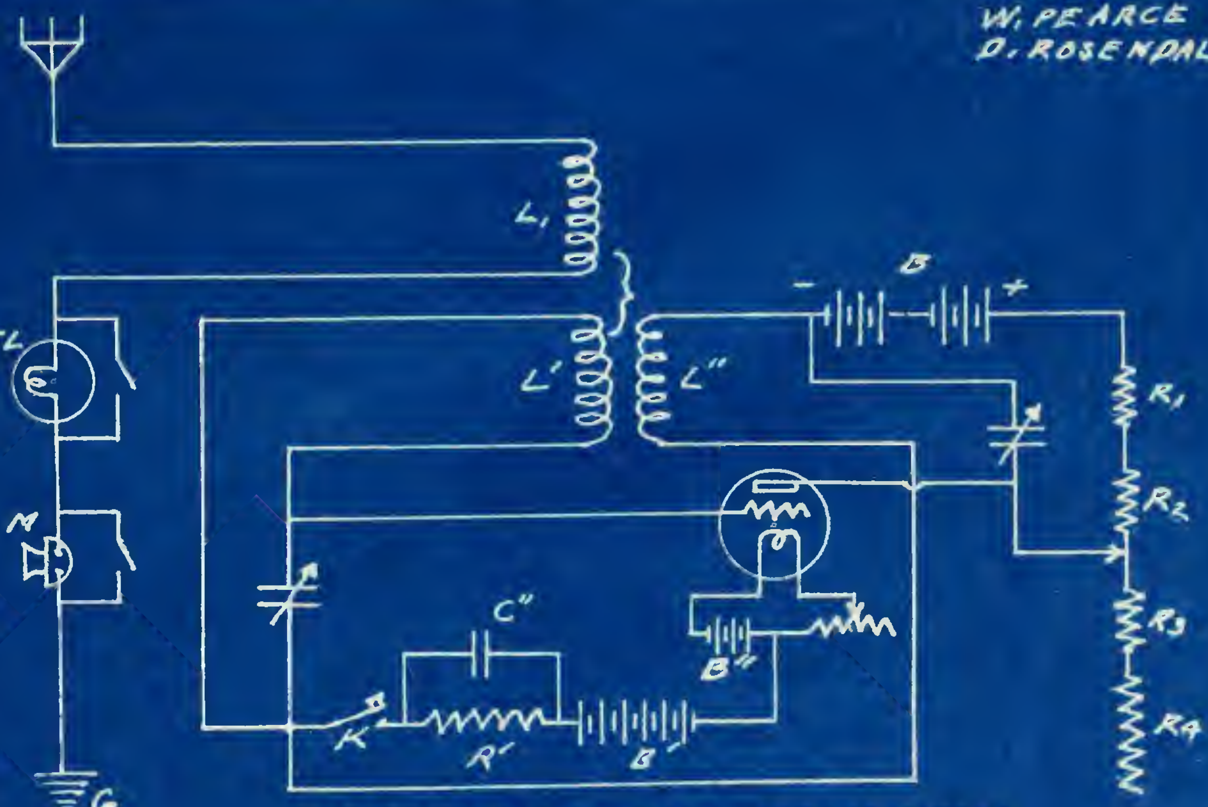


MARCONI RADIOPHONE TRANSMITTER

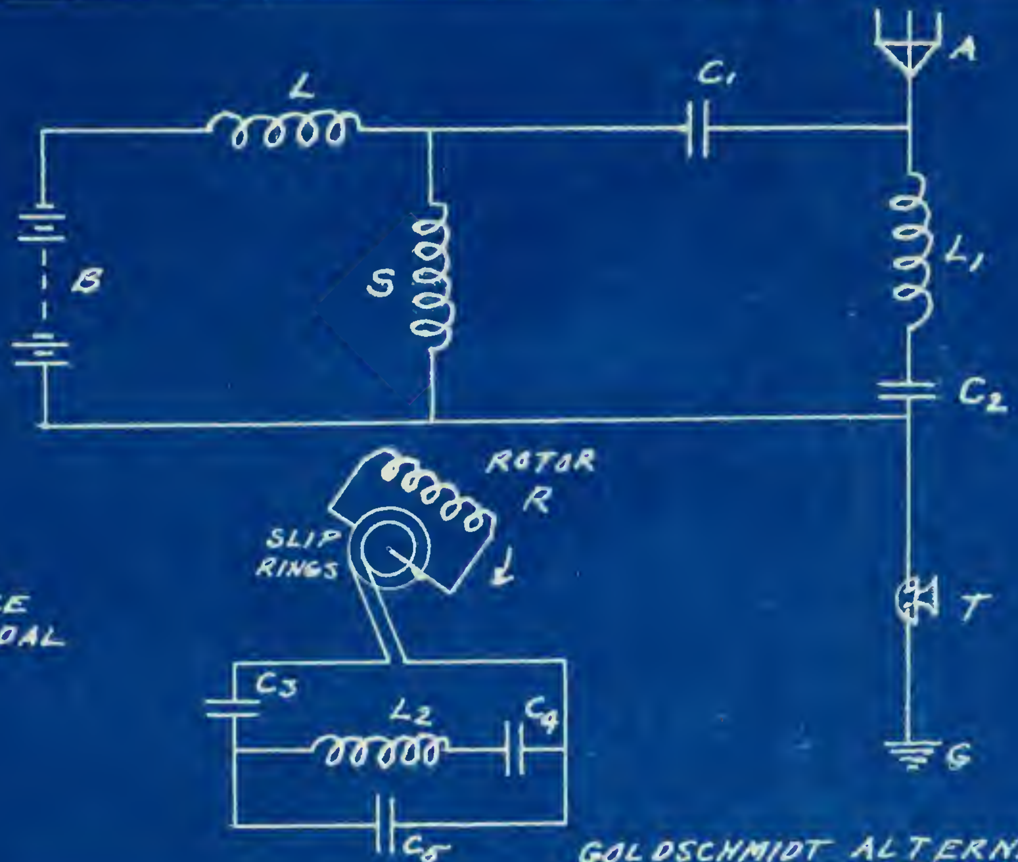
FIG. 7

with these is the plate battery, "B," of 500 volts. The aggregate resistances and battery is shunted by the capacity "C′" of the plate oscillating circuit. The radio frequency energy thus produced is transferred to the antenna circuits at "L′" by an inductive coupling. The presence of oscillations in the antenna is indicated by glowing of the test lamp "TL" which can be short circuited when not in use. The microphone, "M", is directly inserted in the antenna circuit, and can also be short-circuited for purposes of tuning. The battery, "B″," used for lighting the filament, is an ordinary 80 ampere hour storage battery. The battery "B " for providing 500 volts consists of four cases of dry cells. These were found suitable for the needs of the occasion since only 10 to 20 milliamperes were required. The input is from 5 to 10 watts. This is an example of the general type of vacuum tube radiophone set. Most of the successful types are modifications of the above type.

(4) Alternators of Radio Frequency

The big problem with this method is the construction of a suitable and dependable alternator which will produce an alternating current of the extremely high frequency necessary (100,000 to 200,000 cycles). However, several of these have been brought out lately. These are all of the inductor type, because of their necessary high peripheral speed. The Goldschmidt is one of the best of these. In this machine the frequency is doubled within the machine by the combination of a to and fro motion with a rotation. The diagram is shown in Figure 8.

Needless to say, the direct generation system is very simple and thus has many advantages over the ordinary arc sets.



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GOLDSCHMIDT ALTERNATOR

FIG 8

4. THEORY OF VACUUM TUBES

According to the theory now in vogue concerning the ultimate nature of matter, an atom consists of a definite number of electrons grouped about a nucleus having a positive charge. Now so long as none of the electrons is driven from the atom, the latter possesses no detectable electrical charge.

But now let an electron be detached from the atom, then the atom becomes what is known as a "positive ion" and it exhibits the properties of a positively charged body.

Similarly, if an electron is added to a normal uncharged atom, the latter, in this state, possesses a negative charge and is termed a "negative ion." In summarizing, we may say the positive ion possesses a deficiency of electrons and the negative ion an excess of electrons.

Now, in order to liberate the electrons from an atom we must disrupt or tear apart the latter. The vacuum valve forms one of the best examples of a method for accomplishing this.

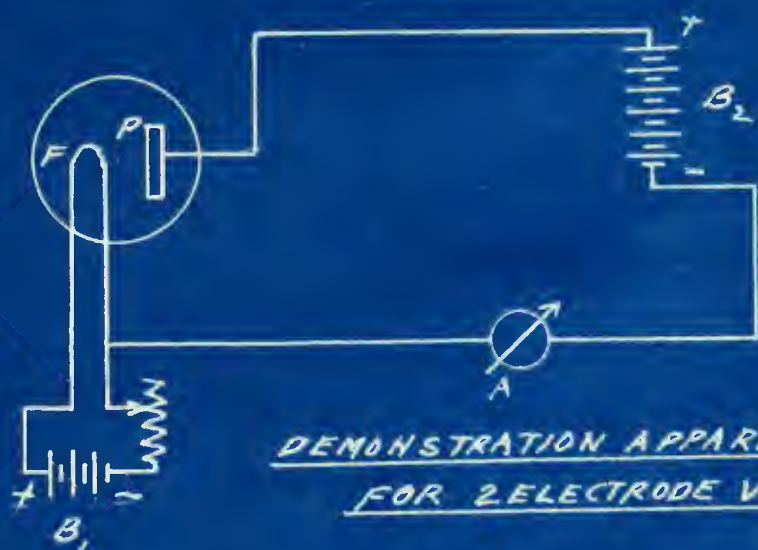
It has been known for many years that the space about a heated metal is a conductor of electricity. It has been demonstrated more recently that it is due to the release of electrons and that if an incandescent metal is placed in a bulb exhausted of air or gases, pure electrons are liberated from the metal. This is the most convenient method for driving electrons from a metallic body for use in connection with oscillation detectors, and as stated before, the other methods for doing this will be out of order.

For useful results the vacuum must be of a high order similar to that of an incandescent lamp or better, as the presence of any considerable quantity of gas either prevents or greatly interferes with a useful action.

The first to employ the emission of electrons from heated metals, to rectify or to detect radio frequency oscillations in a wireless telegraph receiver, was Dr. J. A. Fleming of London. He named his product a glow lamp oscillation detector or oscillation valve, the latter name be-

ing adopted because he found that the lamp conducted better in one direction than in the other. This unilateral conductivity or assymetric resistance was a most important step in the progress of the radio art.

The rectifying properties of the vacuum tube can be demonstrated by the apparatus indicated in the diagram of Figure 9. Here, filament, "F," is heated to incandescence by battery, "B," of 4-12 volts. An e. m. f. variable up to 100 volts or more is applied between "F" and "P" by battery, "B-2." A milliammeter shown at "A" is connected in series with "B_2." Now by charging the plate to a positive potential electrons are drawn over from the filament. In this experiment the meter "A" will register only when the positive terminal of battery "B_2" is connected to the plate. If connected in the opposite way, little or no current will flow. Hence, if an alternating e. m. f. is impressed across "F" and "P," current can flow from "P" to "F" only when "P" is charged positively. The tube thus



DEMONSTRATION APPARATUS
FOR 2 ELECTRODE VALVE

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FIG. 9

becomes a rectifier of alternating currents, and will perform this function at any frequency up to several million cycles per second.

It can also be shown by means of Figure 9 that the conductivity of the space between "P" and "F" is not a constant in the direction in which it conducts more freely, in other words, the apparent resistance varies with the applied e. m. f. This can be shown as follows: If the battery "B_2" is shunted by a potentiometer and the voltage is steadily increased from a small value to some upper limit of the battery, the readings of the meter "A" will not accord with Ohm's law.

During the first increase in voltage, the reading of the current will be low, indicating a high value of resistance, and after a more or less critic-l point is passed, the current will rapidly increase, indicating a much lower resistance. The current voltage readings thus obtained can be plotted in the form of a curve. At a certain point an increa-e in plate voltage does not increase the current. At this point

the valve is said to be saturated.

The reasons for the valve becoming saturated are temperature limitations of the filament, and the space charge, so called. Now the amount of current flowing from plate to filament varies directly with the supply of electrons. In fact, it is assumed that 10^{19} electrons passing from "F" to "P" per second are the equivalent of one ampere. Now as the supply of electrons varies with the temperature is is evident that only the supply of electrons corresponding to maximum filament current can flow regardless of plate voltage.

Dr. Langmuir says that the plate current is limited for a given plate voltage by reason of the space charge within the bulb. He remarks that the electrons flowing between the filament and the plate constitute a negative electric charge in space which repels the electrons escaping from the filament, causing some of them to return to the filament; that is, only a part of the electrons emitted by the filament reach

the plate, the remainder being repelled by the electrons in space returning eventually to their source.

The three electrode valve is shown in Figure 10. The new electrode is called the grid. Its development is credited to Dr. Lee De Forest. The grid electrode when placed in between the filament and plate has its potential lowered and therefore obstructs the flow of electrons so that less escape to the plate, in fact, the current may be completely cut off by giving the grid a sufficient negative e. m. f.

A recent development in the design of the three electrode vacuum bulb is the dynatron. The fundamental construction is shown in Figure 11. The tube contains a filament, "F," a perforated anode, "A," and a plate, "P."

One of the peculiar operating characteristics of the dynatron is that within a certain region of voltages applied to the plate circuit, the device acts as a simple rectifier, but at other values of plate voltage it acts as a true <u>negative resistance</u>, that is, an applied e. m. f.

FLEMING 2-ELECTRODE VALVE

DE FOREST 3-ELECTRODE VALVE

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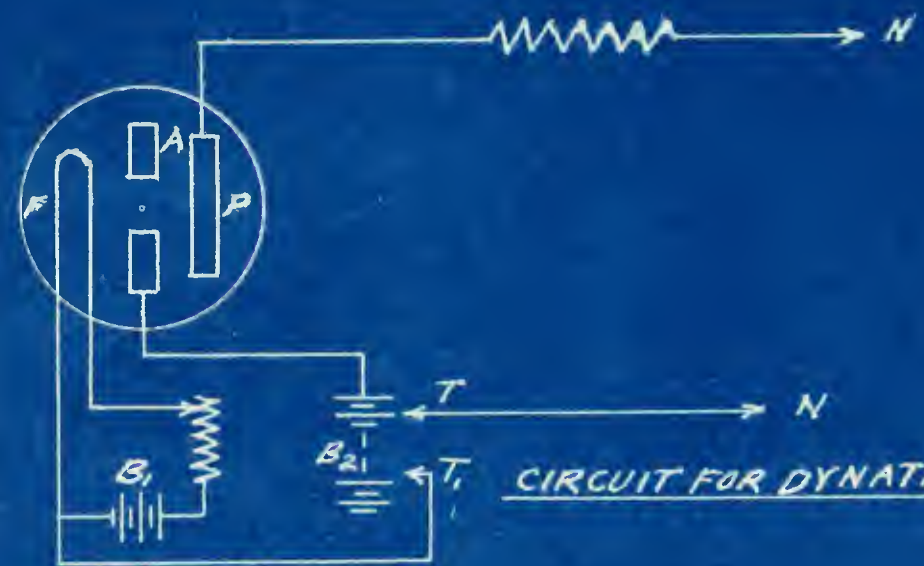
FIG. 10



CIRCUIT FOR DYNATRON TUBE

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FIG. 11

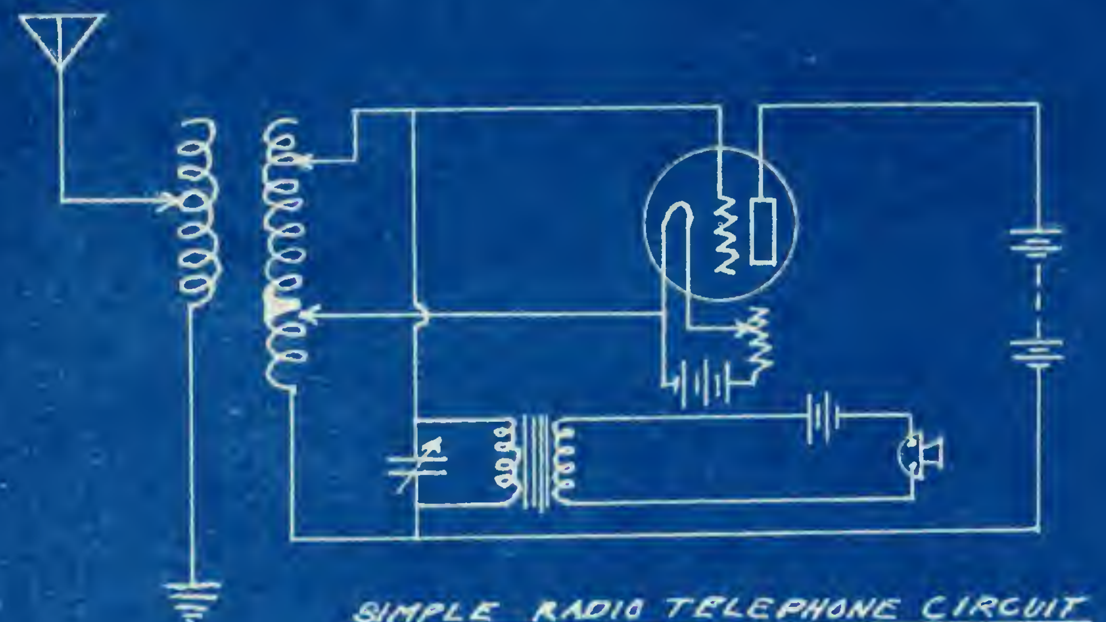
will set up a current in the wrong direction.

The dynatron may be used for an amplifier, oscillator, or detector. In addition it may be used to make up for circuit losses. In the latter role its negative resistance neutralized the natural positive resistance of the circuit causing great amplification.

The Pliotron is merely a sturdily built three element bulb having two plated placed one on either side of the filament and connected together. The grid is a wire wound around the filament just inside of the two plates.

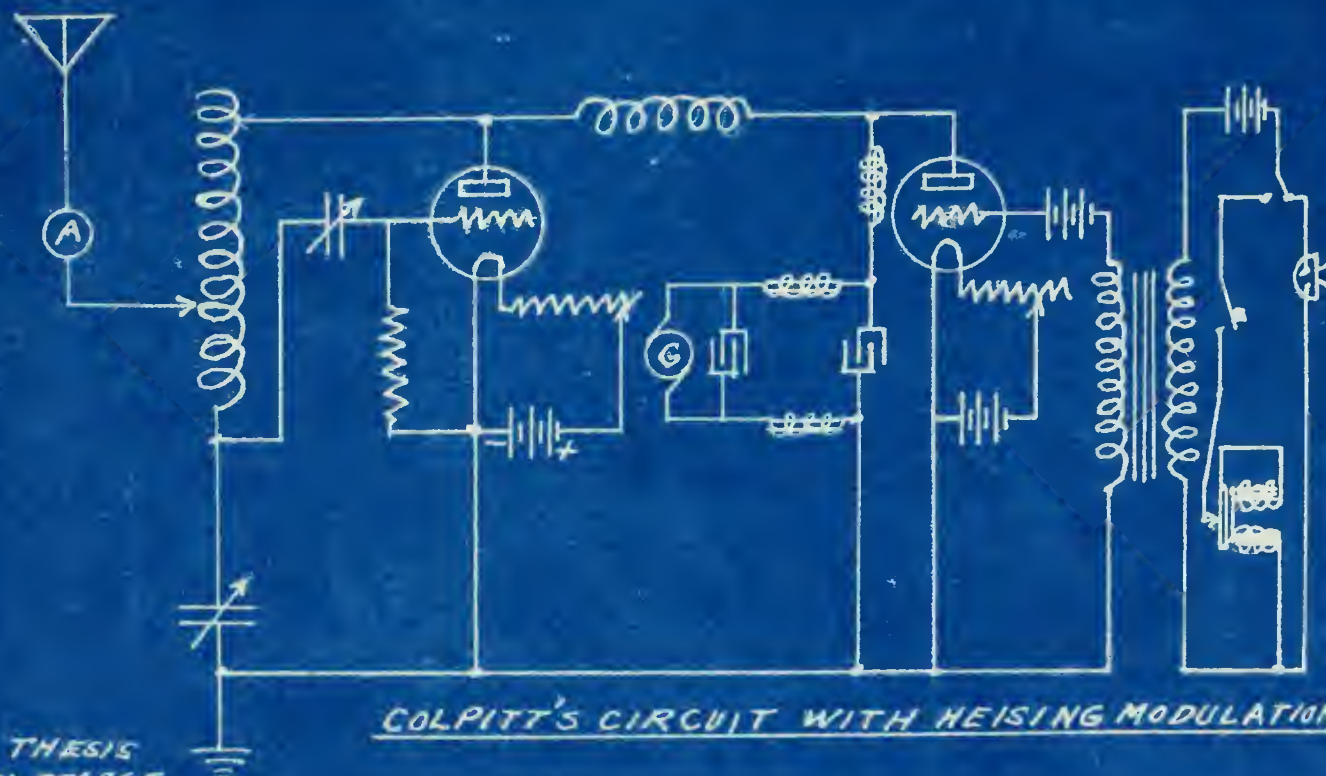
The Pliotron is much used for wireless telephone transmission as a producer of high voltage radio frequency currents. A simple wireless telephone circuit is shown in Figure 12. A more elaborate one is shown in Figure 13. This latter circuit has two bulbs instead of one.

The circuit used in the construction of the set under discussion is explained in the following section together with the diagrams.



SIMPLE RADIO TELEPHONE CIRCUIT

FIG. 12



COLPITT'S CIRCUIT WITH HEISING MODULATION

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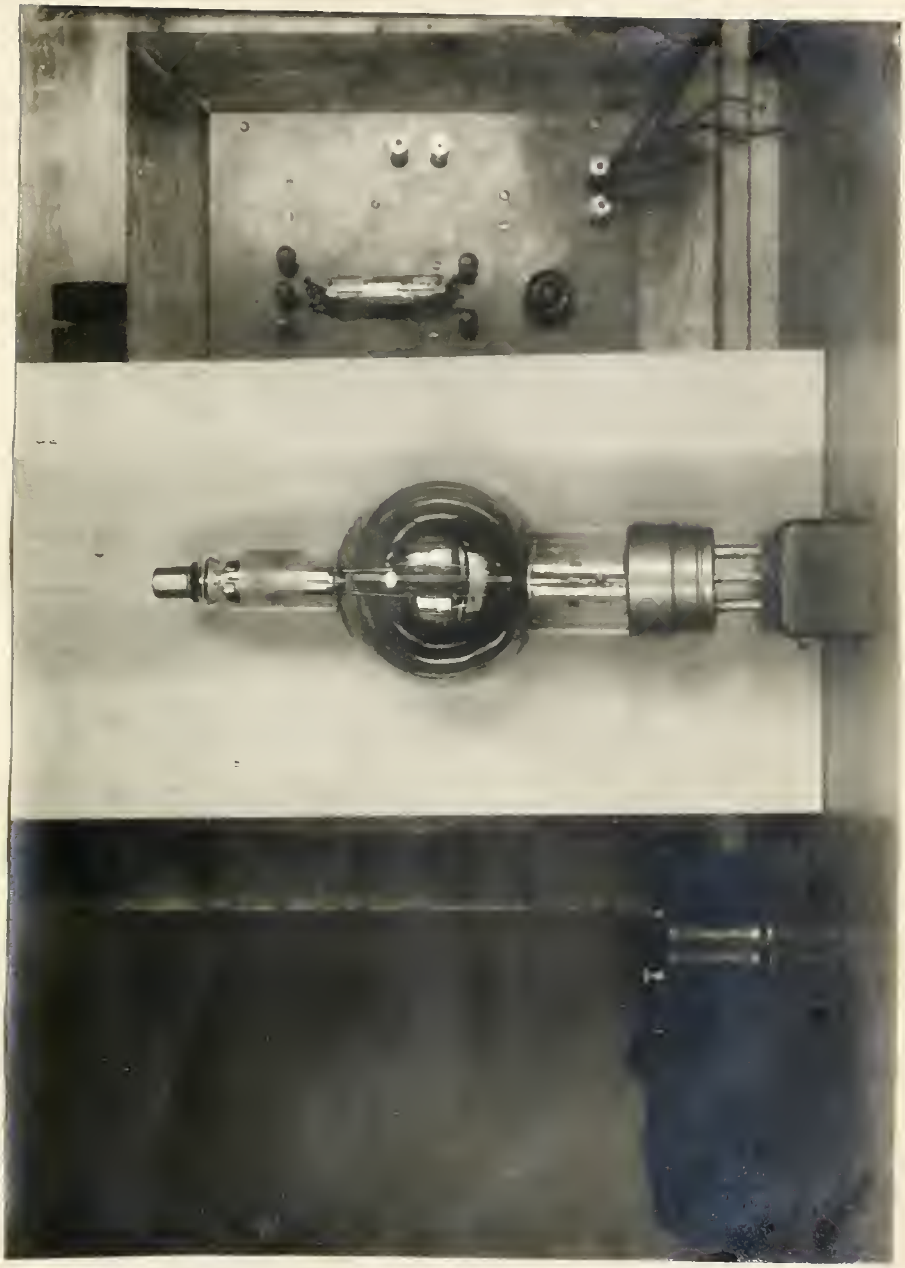
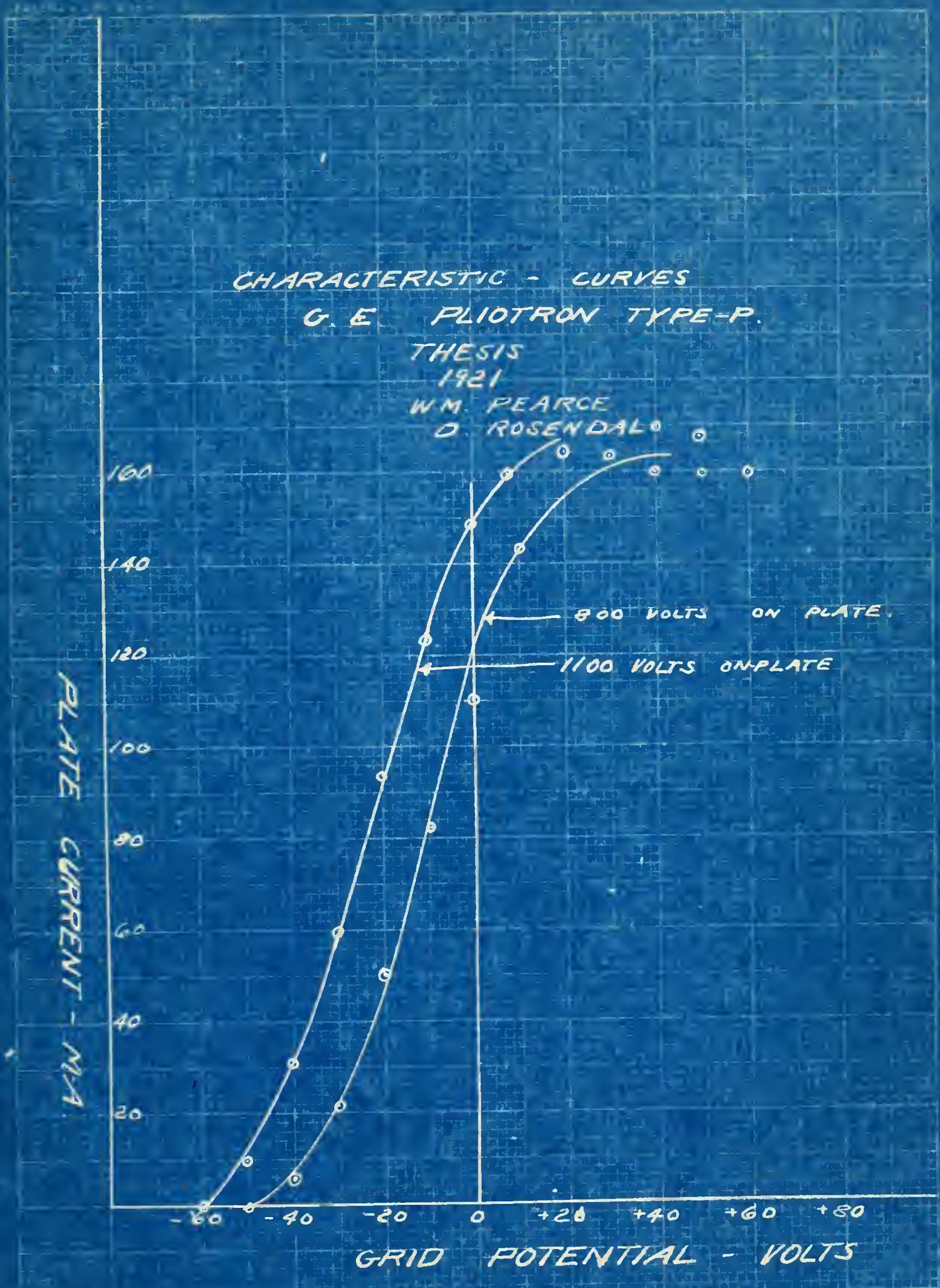
FIG. 13



5. TRANSMITTER

Inasmuch as we had available a General Electric Company Power tube, we decided to use it as our source of undamped waves. This tube is the one shown in the accompanying photograph.

This type P-Pliotron is rated at 350 Watts normal power input to plate circuit. If power over 350 Watts is to be handled, artificial cooling should be resorted to. A fan may be used for this purpose. When in operation the tube should be either in the vertical or horizontal position. In the horizontal position the plates should lie in a vertical plane with the seal off tip downward. Care must be exercised when the tube is hot. Contact with cool bodies may crack the glass, thus destroying the successful operation of the tube. The filament is designed to take 3 to 6 amperes at a pressure of from 16 to 18 volts. Various tubes vary within this range. The makers of the Pliotron recommend the current



CHARACTERISTIC - CURVES
G. E PLIOTRON TYPE-P.
THESIS
1921
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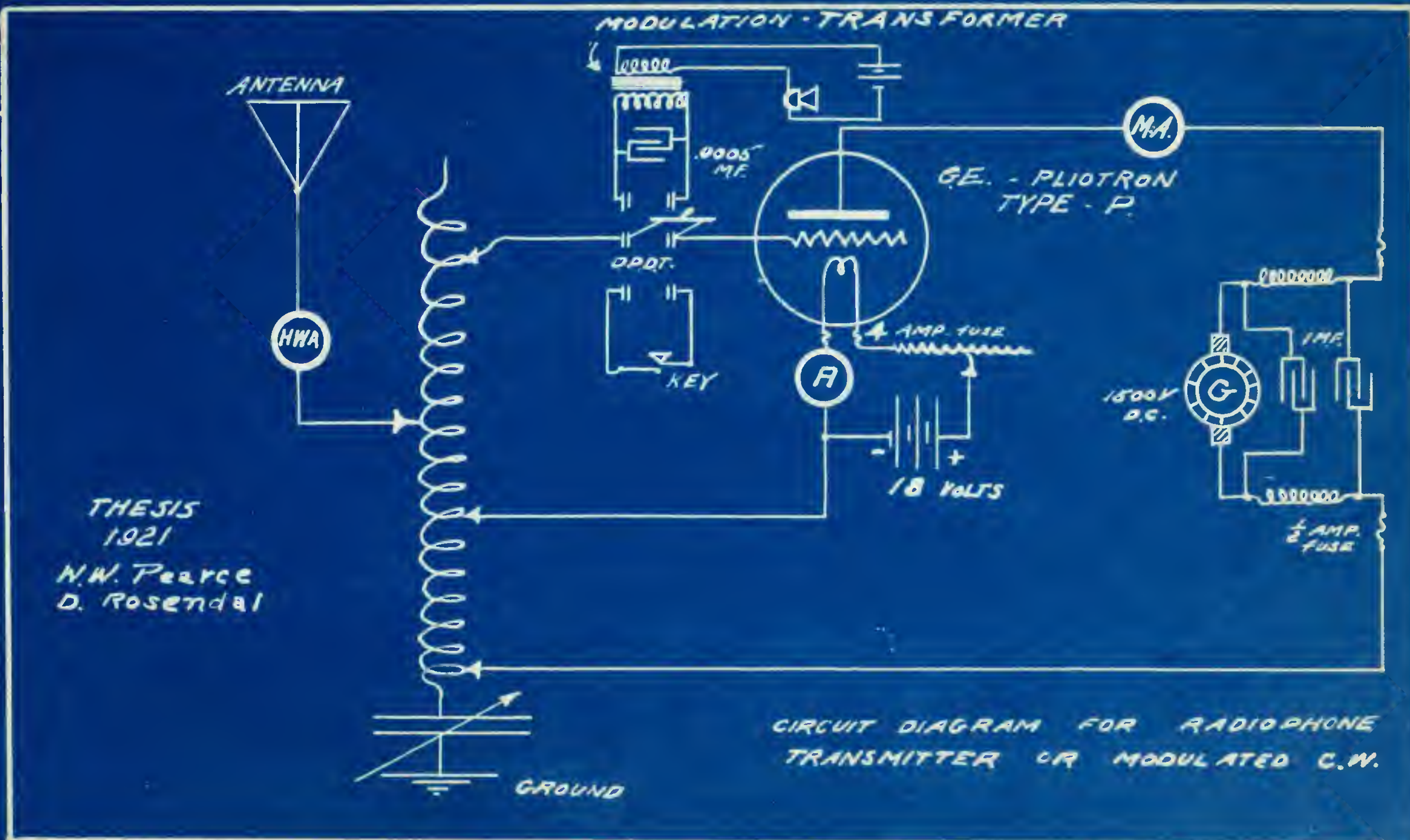
800 VOLTS ON PLATE.
1100 VOLTS ON PLATE
160
140
120
100
80
60
40
20
-60
-40
-20
0
+20
+40
+60
+80
PLATE CURRENT - MA
GRID POTENTIAL - VOLTS

limit at 3.6 amperes, but for small power this value should be lowered as much as possible so as to increase the life of the filament. Tubes of this class are listed at $110.00 on the market to-day so that it is easily seen that economy in filament current is justifiable. The life of a filament decreases very rapidly as the value of the current increases.

Voltages as high as 2500 may be used on the plate of this tube; 1500 volts was used and produced an input in the plate curcuit of 375 Watts with filament current of 3.5 amperes. The characteristic curves of this pliotron are shown on an accompanying page.

We have mounted the tube in a vertical position, the plate terminal being at the top. The accompanying figure shows the circuit arrangement chosen for the transmitter. The D. C. high voltage source is a 1500 volt D. C. Crocker Wheeler Motor-Generator. The Motor side is a 110 volt D. C. Motor, shunt wound. The generator is wound for 1500 volts D. C., shunt field


MODULATION - TRANSFORMER
ANTENNA
.0005 MF
G.E. - PLIOTRON
TYPE - P.
M.A.
D.P.D.T.
HWA
KEY
A
4 AMP. FUSE
1 MF
1500 V D.C.
G
- +
18 VOLTS
½ AMP. FUSE
THESIS
1921
N.W. Pearce
D. Rosendal
CIRCUIT DIAGRAM FOR RADIOPHONE
TRANSMITTER OR MODULATED C.W.
GROUND

excitation. This was the only source available for our use. There are 22 commutator segments on the generator side of the motor generator set.

When using a generator for D. C. source on a telephone transmitter, it is necessary to filter out the hum due to the commutator ripple. This is done by means of a tuned shunt. The tuned shunt is connected across the generator terminals. If tuned to the frequency of the disturbance at the brushes the distrubance will be absorbed by the tuned circuit. The circuit consists of inductance and capacity. As shown by the circuit diagram the tuned circuit used in this case consisted of two condensers and two inductances. The inductances are wound on iron cores and are connected in series with the out-going line. The condensers are of about 1 m. f. capacity, and are mica insulated. Paper insulated condensers were not found practicable at such high voltages. The telephone condenser of 1 m. f. capacity is not suitable for voltages much above 200. The condensers used were the only

ones available and weighed considerably over 150 pounds.

More than one filter was not tried because condensers were not available.

One-half ampere fuses are placed in the lines to prevent damage to the generator in case of over load or accidents.

The milli-ammeter shown is capable of reading up to 500 milli-amperes.

The filament circuit is protected by means of a four ampere fuse.

Twenty-four volts is used for the filament source and is cut down to the required voltage through a rheostat mounted upon the face of the transmitting panel. An ammeter is connected in series with the filament current. The filament voltage source has a ground return which necessitated the use of a variable condenser in the ground lead of the radiating circuit. This variable condenser is a large rotating plate condenser of very substantial construction.

The inductance is shown in the photograph

on the right. Direct coupling was chosen as the most efficient. Results in experiments carried on with inductive coupling did not approach those obtained with direct coupling.

The five connections to the inductives are soldered to clips. Tuning them is accomplished by moving the clips up or down the coil. This inductive is three feet in length, six inches in diameter, mounted on a wooden frame. Turns are spaced about 1/4 inch apart. Ground is obtained through a water and a gas pipe. A hot wire ammeter 0 to 5 is placed in the antenna circuit.

The antenna is a T aerial strung between the Mission Building and Chapin Hall. It is about fifty feet offthe earth. The natural period of this aerial circuit is about 175 meters.

The wave length of the wave used is 300 meters. The increase in wave length is due to the additional inductance of the tuning coi_.

The amateur wave length is 200 meters in the United States but the Armour Institute of Technology has been issued a special license by the government which gives the school the right to use wave lengths above 200 and up to 600 meters. Use of the 200 meter wave entails interferrence with other stations of that wave length. Greater distances and less interferrence may be had at the 300 meter wave than at the 200 meter wave length.

The transmitter istuned for maximum radiation at 300 meters, but 250 meters or 275 may be used by adjusting the variable condenser in the ground lead. At 250 and 275 meters cless antenna current flows for the same adjustments of inductance as used on the 300 meter wave.

Modulation

In order to produce fluctuations in the oscillations of a vacuum tube transmitter either the plate potential or grid potential is modified. Small tube transmitters require but small voltage variation on the plate or

grid circuits to produce a well modulated wave.

With the use of very high plate voltages, the characteristic of a vacuum tube does not change appreciably. An accompanying curve sheet shown two of the characteristic curves of this type P Pliotron. This curve shows what a large grid potential is necessary to produce a change in the plate current.

Suitable means must be provided for supplying this large e. m. f. to the grid or plate for successful modulation of the carrier wave.

A Western Electric Company modulation transformer with a high secondary impedance was employed. The ratio of secondary turns to primary turns is about 500 to 1.

The primary coil is connected in series with a three cell Edison storage battery and a Microphone transmitter. Variations of the Microphone current produce corresponding vibrations on the grid circuit of very much increased voltage. The impedance of the second-

ary being very high, high frequency oscillations would be choked out so it was necessary to shunt the secondary of the modulation transformer with a variable condenser of .0005 microfarad capacity.

A D. P. D. T. switch is used to throw from radio phone to undamped transmission. The connection is clearly shown in the circuit diagram accompanying.

A Key is used in the grid circuit for transmission. Providing the commutator ripple is filtered out straight, continuous wave transmission may be carried on with this system. If the ripple exists, a modulated wave will be transmitted, the continuous wave acting as a carrier for the ripple.

Tuning is accomplished by cut and try method. The five clips leading to the inductance are adjusted for maximum radiation for the desired wave length. A hot wire ammeter suitable for measurement of high frequency current is used in the antenna circuit for measurement of the antenna current.

Operation of Transmitter

With Key depressed the circuits were tuned for a 300 meter wave length. A wave meter held adjacent to the ground lead indicated a wave length of 300 meters.

Final adjustment indicated an antenna current of 2-1/2 amperes, the filament current ammeter reading 3.5 amperes and the plate e. m. f. being 1500 volts, and the plate current reading was 250 milli-amperes.

Arrangements for a test with a station a few miles distant were made. First transmission was carried on by Key, then the telephone was used.

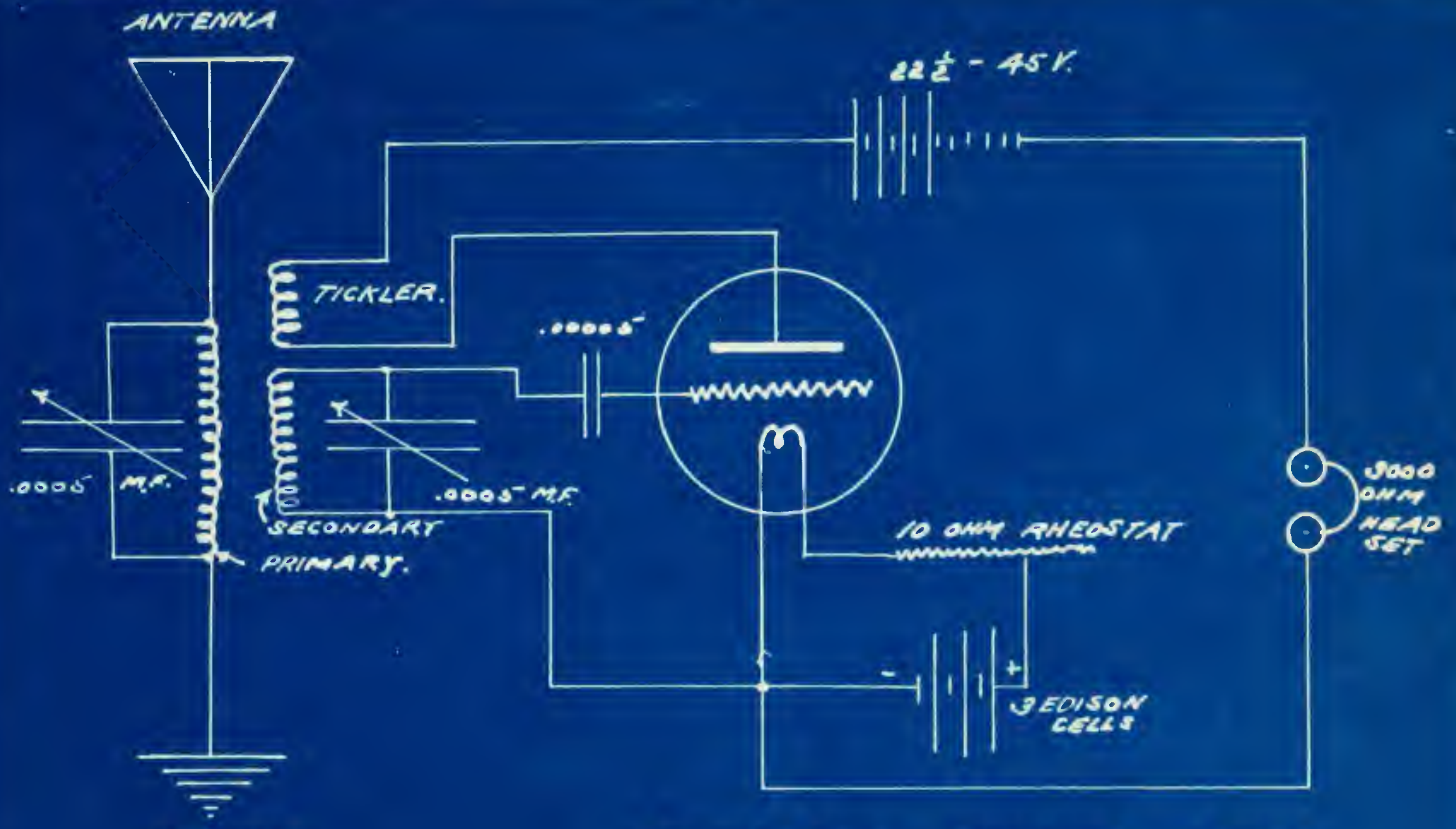
The continuous wave was successfully modulated by the telephonic speech, but great difficulty was experienced in receiving the speech because of the inability to rid the circuit of the commutator ripple.

The main D ripple has a frequency of about 330 cycles per second. When using D. C.

Generators for telephonic transmission, it is customary to use machines having a very large number of commutator segments as this raises the note of the ripple above that ordinarily used in phone work. The machine used in this case had but 22 segments. This machine, no doubt, possesses a few harmonics which were readily noticed during the test.

While using the Key as a transmitter the C. W. was modulated by the commutator ripple in good style. Signals were reported very loud in the city of Chicago and outlying districts.

With 2-1/2 amperes radiation on C. W. no difficulty should be experienced in transmitting 1000 miles using the Key as transmitter on good nights. The same distance should be reached with the phone modulation providing suitable high voltage direct current were available.



REGENERATIVE RECEIVER CIRCUIT

THESIS

1921

W.W. PEARCE

D. ROSENDAL.

6. RECEIVER

Reception of radio phone signals is not quite as difficult as it locks. Reception of the carrier wave is more difficult then reception of the voice modulated oscillation. Voice modulated C. W. may be received as easily as damped wave telegraph signals.

Crystal detectors may be used, but are not as sensitive as the vacuum valve detectors. For short distances, the crystal detector is cheap and effective, but long distance work necessitates the use of highly sensitive and strong amplifying outfits. With this in view the receiving set described herein was built.

The accompanying figure shows a common regenerative receiver circuit; its principal of operation has previously been described.

A Honeycomb coil mounting was procured for tuning. Three coils are used in this type of receiver,--a primary, secondayy and tickler. The operation of each inductance has been described previously.

Inasmuch as short wave telephony is the most polular at present, inductance coils suitable to the waves of 150 to 650 meters were chosen for the mounting.

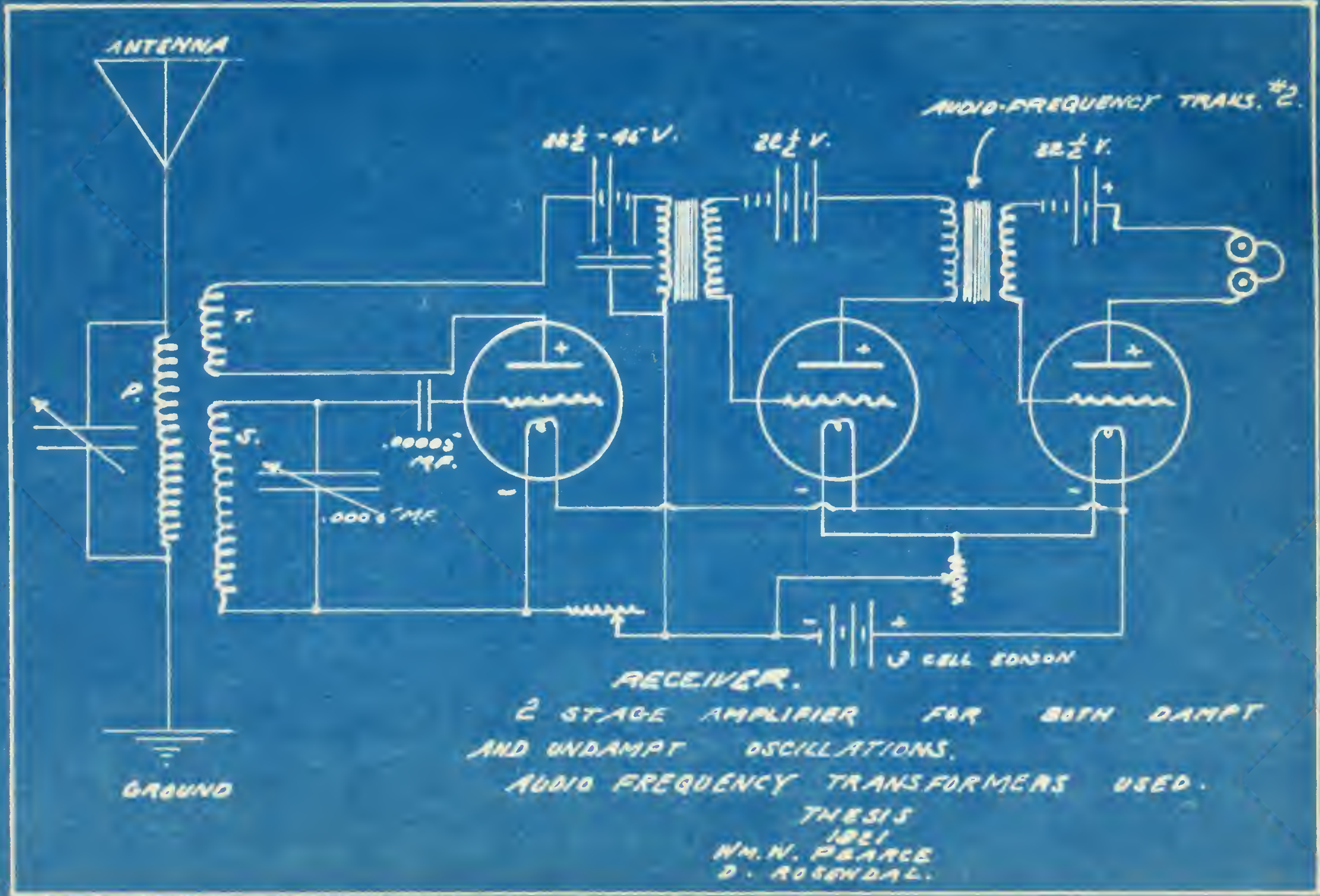
The primary coil has 25 turns.

The secondary coil has 50 turns.

The tickler coil has 35 turns.

These coils are about 2-1/2 inches in diameter, so called because of the peculiar winding, are fixed inductances. In order to tune to various wave lengths, it was necessary to shunt the primary and secondary with variable condensers of .0005 micro-farads maximum capacity.

Other inductances are available for longer wave lengths (650 to 18000 meters). A small micro-farad capacity is inserted in the grid circuit as shown in the circuit diagram. By means of a milli contact switch, the potential on the plate of the detector tube may be varied from 22-1/2 up to 45 volts. This allows of sensitive adjustment. The detector filament current is ad-



RECEIVER.

2 STAGE AMPLIFIER FOR BOTH DAMPT AND UNDAMPT OSCILLATIONS.

AUDIO FREQUENCY TRANSFORMERS USED.

THESIS
1921
WM. N. PEARCE
D. ROSENDAL.

justed by means of a rheostat.

The two amplifier tube filaments are governed by one rheostat as shown in the accompanying circuit diagram.

When using tubes of like characteristics, common filament current and plate potential are commonly used. This fact allows the use of one rheostat for two filaments, inasmuch as the current in each filament will be 1/2 that in the rheostat.

Two G. E. Co. vacuum tubes are used as amplifier tubes. The plate voltage is 22-1/2 on each tube. This plate voltage is supplied by means of a moulded block of small flash light cells. An individual source of plate e. m. f. is used for each amplifier tube.

The detector tube is mounted upon the front of the 1/8 inch bakelite panel by means of five binding posts. There are three binding posts at the top, the two outside ones accommodate the ends of the two filaments, while the

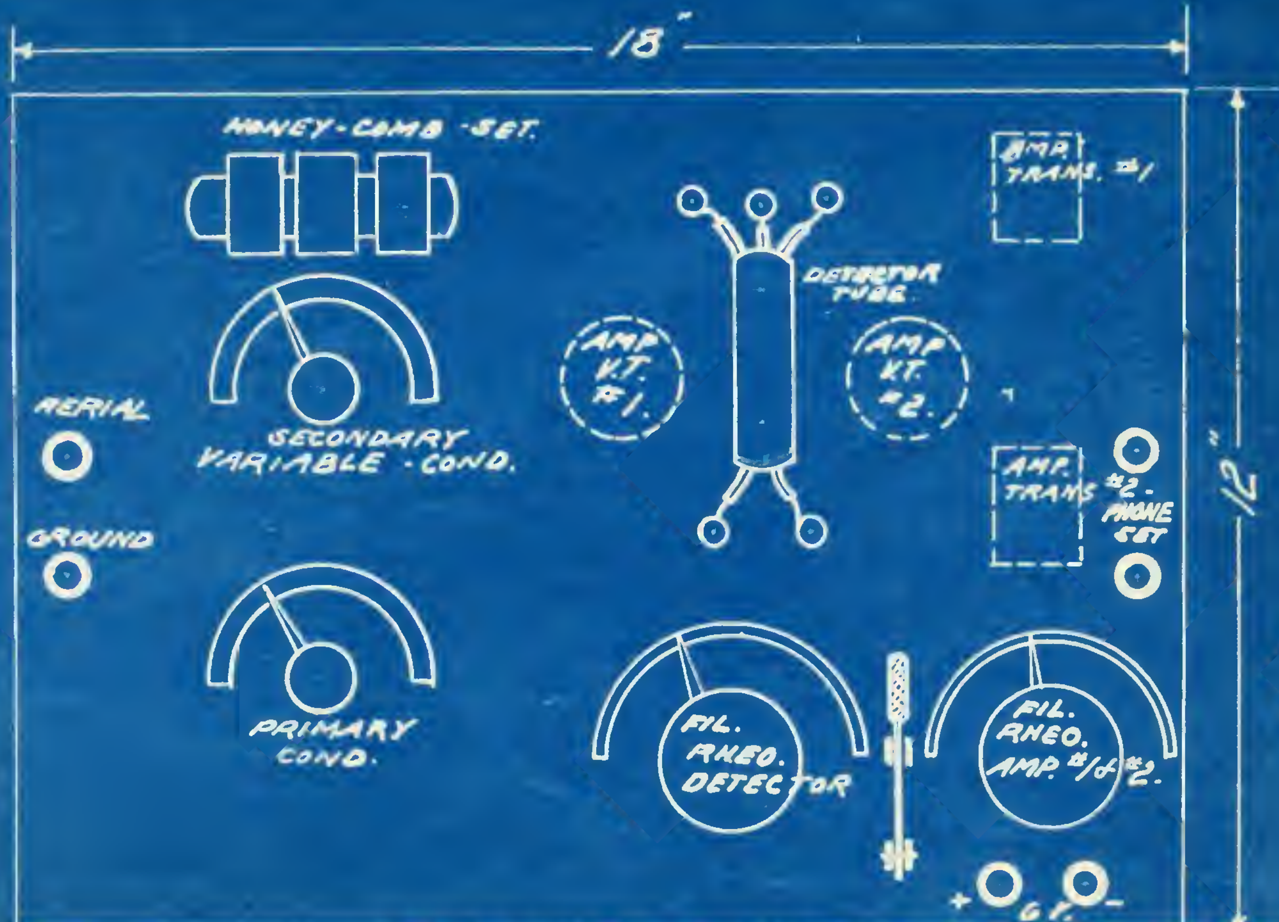
middle one is the grid connection. The two lower binding posts are for the plate and the common return of the two filaments in the tube.

The amplifier tubes are fitted into standard V-T sockets which are fastened upon the back of the panel.

Federal Telephone and Telegraph Company's amplifying transformers are mounted upon the back of the panel as also are the filament rheostats. The knobs of the filament rheostats are mounted on the front of the panel as shown in the photograph of the receiving panel.

The primary and secondary condensers are also mounted on the back of the panel below the honeycomb coil mounting. Adjustment is made by knobs on the front of the panel.

The binding posts at the lower right hand corner of the panel are used for the + and - connections of a three cell Edison storage battery.



RECEIVING - PANEL
1/8" BAKELITE

THESIS
N.N. PEARCE
D. ROSENDAL

The two binding posts situated at the right of the panel are for phone connections and those at the left are for aerial and ground connections.

The telephone receivers employed with this set are Western Electric Company's 2800 ohm phone set. These phones are very light and sensitive.

7. RESULTS

The primary is first tuned by means of the variable condenser across the primary circuit, then the secondary is tuned by means of its variable capacity until the maximum strength of signals is obtained. Critical adjustment of the detector and amplifiers is obtained by manipulating the plate voltage of the detector and the filament currents of the detector and amplifier tubes. A little practice will tell where the correct adjustment of the tubes is to be found. Filament ammeters are not necessary because the sound in the phones is a good indicator of a too heavy filament current. In the detector an excess current causes hissing. The amplifier filament current should be as small as it is possible to make it and still get good signals.

The hook up described above was tried successfully on radio telephone and undamped wave telegraphy.

The telephone picked up was that of a local station transmitting music from a phonograph. Long distance work was out of the question at this time of the year on account of the heavy atmospherics.

Damped wave telegraphy on waves of 200 to 1500 were readily picked up by this set.

Undamped waves were received during the daytime on waves up to 16,900 meters.

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